Gravity-type separators tend to be more effective for wastewater streams with consistently large amounts of surface oil. Drum and belt type skimmers are more applicable to waste streams containing smaller amounts of floating oil. A gravity separator in conjunction with a drum-type skimmer effectively removes floating contaminants from nonemulsified oily waste streams.

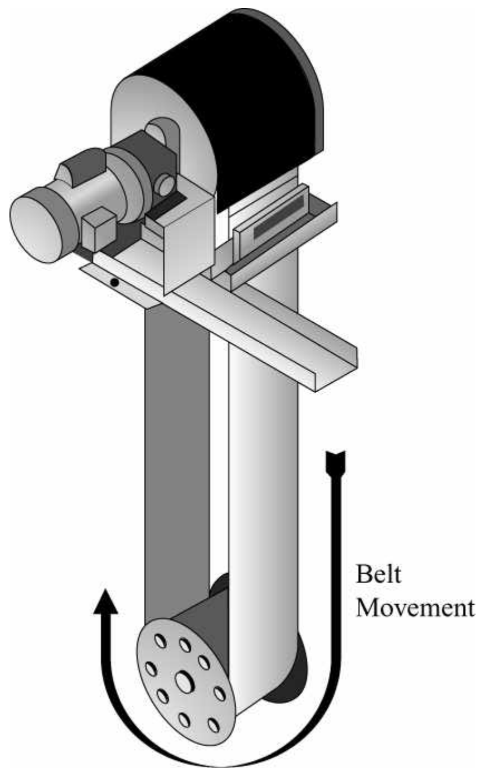

Figure 8-11b.
Belt Oil Skimming Unit

Coalescers remove oil droplets too finely dispersed for conventional gravity separation-skimming technology. Coalescing also reduces the residence times (and therefore separator volumes) required to separate oil from some wastes. The basic principle of coalescence involves the attraction of oil droplets to the coalescing medium (typically plates). The oil droplets accumulate on the medium and then rise to the surface of the solution as they combine to form larger particles. The most important requirements for coalescing media are attraction for oil and large surface area. Coalescing media include polypropylene, ceramic, and glass.

Coalescing stages may be integrated with a wide variety of gravity oil separators, and some systems may incorporate several coalescing stages. A preliminary oil skimming step avoids overloading the coalescer.

Oil separation not only removes oil but also removes organics that are more soluble in oil than in water. Subsequent clarification removes organic solids directly and probably removes dissolved organics by adsorption on inorganic solids. In MP&M operations, sources of these organics are mainly process coolants and lubricants, additives to formulations of cleaners, paint formulations, or leaching from plastic lines and other materials.

8.2.5.3 Flotation of Oils or Solids

Air flotation combined with chemical emulsion breaking is an effective way of treating oily wastewater containing low concentrations of metals. Flotation is used to separate oil and grease from the wastewater, and small amounts of metal will be removed by entrainment or adsorption. In dissolved air flotation (DAF), air is injected into a fluid under pressure. The amount of air that can dissolve in a fluid increases with increasing pressure. When the pressure is released, the air comes out of solution as bubbles, which attach to oil and grease molecules and "float" the oil and grease to the surface. Induced-air flotation uses the same separation principles as DAF systems but the gas is self-induced by a rotor-disperser mechanism.

Figure 8-12 shows a diagram of a DAF unit. A DAF system consists of a pressurizing pump, air injection equipment, pressurizing tank, a pressure release valve, and a flotation tank. DAF systems operate in two modes: full-flow pressurization and recycle pressurization. In full-flow pressurization, all influent wastewater is pressurized and injected with air. The wastewater then enters the flotation unit where the pressure is relieved and bubbles form, causing the oil and grease to rise to the surface with the air bubbles. In recycle pressurization, part of the clarified effluent is recycled back to the influent of the dissolved air flotation unit, then pressurized and supersaturated with air. The recycled effluent then flows through a pressure release valve into the flotation unit. Pressurizing only the recycle reduces the amount of energy required to pressurize the entire influent. DAF is the most common method of air flotation.

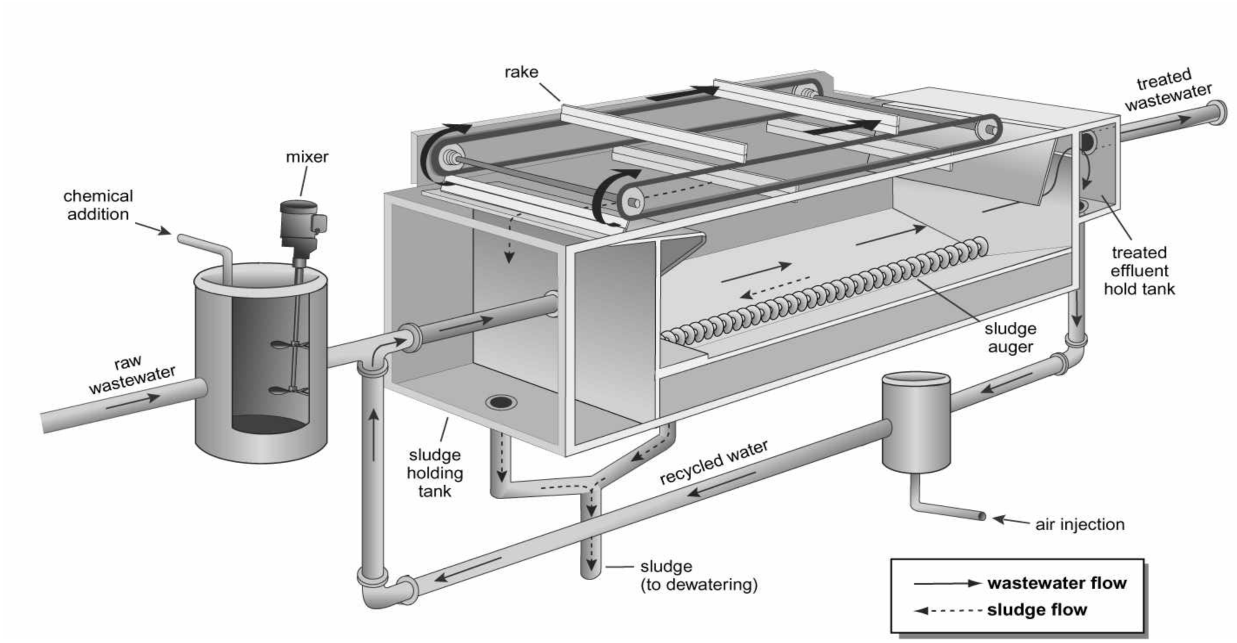

Figure 8-12. Dissolved Air Flotation Unit

8.2.5.4 Ultrafiltration

Ultrafiltration is a membrane-based process used to separate solution components based on molecular size and shape. Using an applied pressure difference across a membrane, solvent and small solute species pass through the membrane and are collected as permeate while the membrane retains larger compounds, which are recovered as concentrate. Figure 8-5 shows a typical membrane filtration unit.

Ultrafiltration typically removes materials ranging from 0.002 to 0.2 microns or molecular-weights from 500 to 300,000. It can be used for the treatment of oily wastewater. Prefiltration of the ultrafiltration influent removes large particles and free oil to prevent membrane damage and fouling. Most ultrafiltration membranes are made of homogeneous polymer or copolymer material. The transmembrane pressure required for ultrafiltration depends on membrane pore size, and typically ranges between 15 to 200 psi.

Ultrafiltration typically produces a concentrated oil phase that is 2 to 5 percent of the influent volume. Oily concentrates are typically contract hauled or incinerated, and the permeate (water phase) can either be treated further to remove water-soluble metals and organics, or be discharged, depending on local and state requirements.

An ultrafiltration system includes: pumps and feed vessels, piping or tubing, monitoring and control units for temperature, pressure, and flow rate; process and cleaning tanks; and membranes. Membranes are specifically designed to handle various waste stream parameters, including temperature, pH, and chemical compatibility. Different types of membranes can be purchased, including hollow fiber, tubular, flat plate, and spiral wound. The type selected depends on the type of application. For example, tubular membranes are commonly used to separate suspended solids, whereas spiral wound membranes are used to separate oil from water. Ultrafiltration designed for oil removal is typically more expensive than dissolved air flotation systems. In terms of maintenance, membranes must be cleaned periodically to ensure effective treatment.

8.3 End-of-Pipe Wastewater and Sludge Treatment Technologies

This section describes end-of-pipe technologies that MP&M facilities can use for wastewater and sludge treatment. Section 8.3.1 discusses metal removal technologies, Section 8.3.2 discusses oil removal technologies, Section 8.3.3 discusses polishing technologies, and Section 8.3.4 discusses sludge-handling technologies.

8.3.1 Metals Removal

The most common end-of-pipe treatment technology used in the MP&M industry to remove dissolved metals is chemical precipitation and flocculation followed by gravity clarification. Microfiltration can be used in place of clarification. The types of equipment used for chemical precipitation vary widely. Small batch operations can be performed in a single tank that typically has a conical bottom to permit removal of settled solids. Continuous processes are usually performed in a series of tanks, including an equalization tank, a rapid-mix tank for dispersing the precipitating chemicals, and a slow-mix tank for adding coagulants and flocculants and for floc formation.

For continuous-flow systems, the first tank in the treatment train is typically the equalization tank. In the chemical precipitation system, the flow equalization tank prevents upsets in processing operations from exceeding the hydraulic design capacity of the treatment system, improves chemical feed control, and provides an opportunity for wastewater neutralization.

Commingled wastewater from the equalization tank enters the rapid mix tank, where various types of precipitation chemicals are added to convert the soluble metals into insoluble compounds. Following precipitation, the wastewater flows into a flocculation tank where polyelectrolytes (polymers) are added, causing the precipitated solids to coagulate into larger particles that can be removed by gravity settling or microfiltration.

Chemical precipitation is a highly reliable technology when proper monitoring and control are used. The effectiveness of metal precipitation processes depends on the types of equipment used and numerous operating factors, such as the characteristics of the raw wastewater, types of treatment reagents used, and operating pH. In some cases, operational factors need to be optimized to achieve sufficiently low effluent concentrations. Often, subtle changes such as varying the pH, altering chemical dosage, or extending the process reaction time may sufficiently improve its efficiency. In other cases, modifications to the treatment system are necessary. For example, some raw wastewater contains chemicals that may interfere with the precipitation of metals, which may require additional treatment reagents such as ferrous sulfate, sodium hydrosulfate, aluminum sulfate, or calcium chloride. These chemicals may be added prior to or during the precipitation process.

Chemical precipitation systems require routine maintenance for proper operation. Routine maintenance includes: calibrating instrumentation and cleaning probes; maintaining chemical pumps and mixers (inspection, cleaning, lubrication, replacing seals and packing, replacing check valves, cleaning strainers); and monitoring tanks and sumps (inspection, cleaning, corrosion prevention). There are several basic methods of performing chemical precipitation and flocculation and many variations of each method. The four most common methods are described below. Figure 8-13 shows a typical continuous chemical precipitation system.

Hydroxide Precipitation. Hydroxide precipitation is the most common method of removing metals from MP&M wastewater. This process is typically performed in several stages. In an initial tank, which is mechanically agitated, alkaline treatment reagents such as lime (calcium hydroxide or hydrated lime), sodium hydroxide, or magnesium hydroxide are added to the wastewater to precipitate metal ions as metal hydroxides. The reaction for precipitation of a divalent metal using lime is shown in the following equation:

$$M^{2+} + Ca(OH)_2 \rightarrow M(OH)_2 + Ca^{2+} \qquad \textbf{(8-7)}$$

The precipitation process is usually operated at a pH of between 8.5 and 10.0, depending on the types of metals in the wastewater. The pH set point is selected by choosing the value at which metals are most effectively removed. Figure 8-14 shows the effect of pH on hydroxide precipitation. As shown in this figure, most metal hydroxides have an optimum pH (i.e., a minimum solubility point) at which the metal is most effectively precipitated.

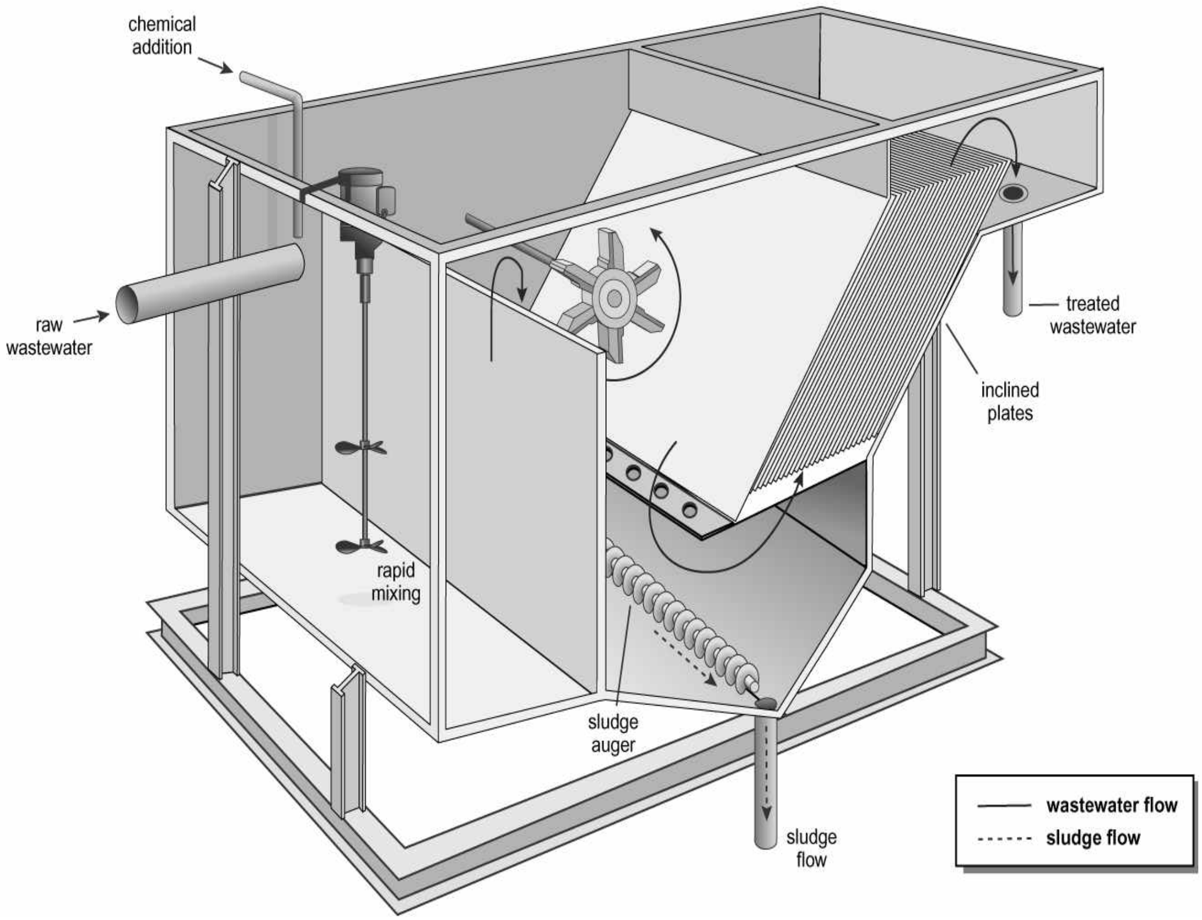

Figure 8-13. Continuous Chemical Precipitation System with Lamella Clarifier

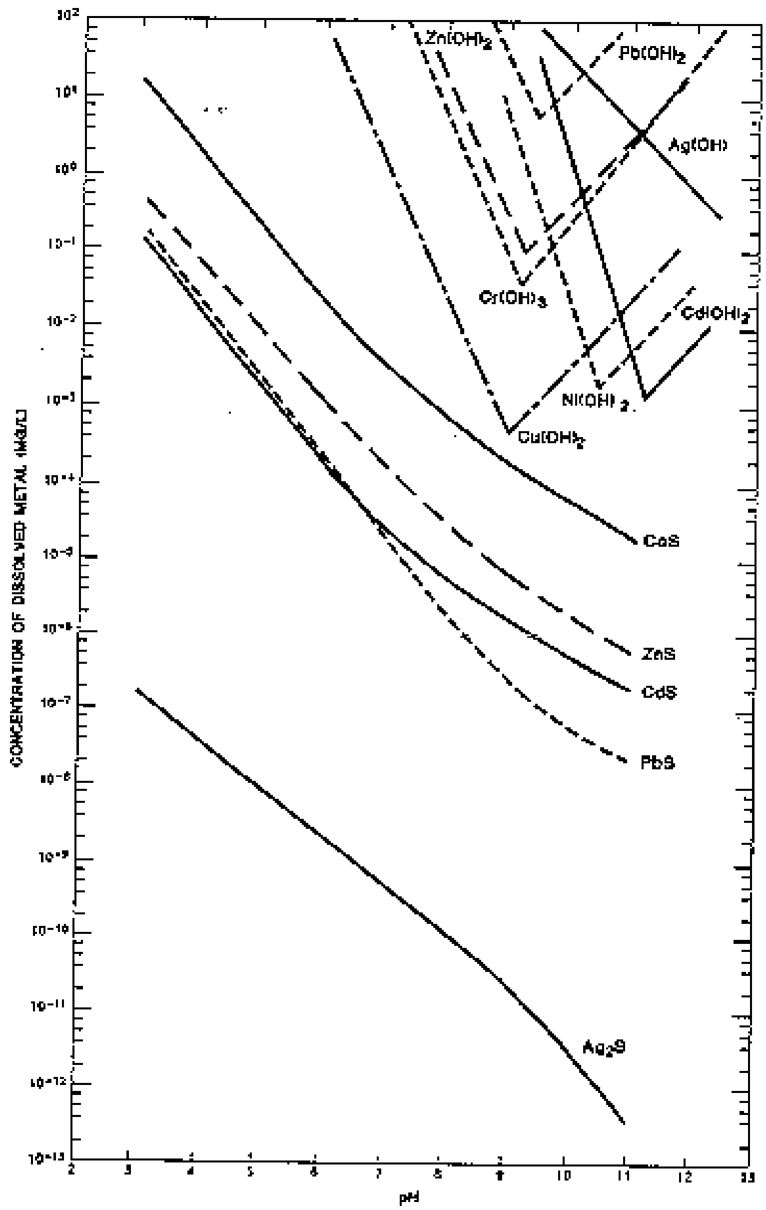

Figure 8-14. Effect of pH on Hydroxide and Sulfide Precipitation

After precipitation, the metal hydroxide particles are very fine and resistant to settling. To increase particle size and improve the settling characteristics of the metal hydroxides, coagulating and flocculating agents are added, usually in a second tank, and slowly mixed. Coagulating and flocculating agents include inorganic chemicals such as alum and ferrous sulfate, and a highly diverse range of organic polyelectrolytes with varying characteristics suitable for different wastewaters. The particles are then settled in a separate clarification tank (e.g., a lamella clarifier), under quiescent conditions, using the difference in density between the solid particles and the wastewater. The solids are removed from the bottom of the settling tank or clarifier, then transferred to a thickener or other dewatering process (see Section 8.3.4). The effluent is either further processed in a polishing unit or discharged.

Sulfide Precipitation. The sulfide precipitation process uses equipment similar to that used for hydroxide precipitation. The major difference between the two processes is the treatment reagents used. Sulfide precipitation uses either soluble sulfides (e.g., hydrogen sulfide or sodium sulfide) or insoluble sulfides (e.g., ferrous sulfide) in place of alkali reagents used in hydroxide precipitation. The sulfide reagents precipitate dissolved metals as metal sulfides, which often have lower solubility limits than metal hydroxides. Therefore, the sulfide precipitation process can (for many metals) reduce the levels of residual dissolved metal in the treated effluent (see Figure 8-14). The sulfide precipitation reaction is shown in the following equation:

$$M^{2+} + FeS \rightarrow MS + Fe^{2+} \qquad \textbf{(8-8)}$$

Unlike hydroxides, sulfide can precipitate most chelated metals and can remove hexavalent chromium without first reducing the chromium to its trivalent state.

The major disadvantages of sulfide precipitation as compared to hydroxide precipitation are higher capital and operating costs and larger sludge generation rates due to the precipitation of ferrous ions. Additional disadvantages of sulfide precipitation are the potential for toxic hydrogen sulfide gas generation, the potential for excessive sulfide releases in the effluent, and the generation of sulfide odors.

Carbonate Precipitation. Carbonate precipitation typically uses sodium carbonate (soda ash), sodium bicarbonate, or calcium carbonate to form insoluble metal carbonates. The reaction is shown in the following equation:

$$M^{2+} + Na_2CO_3 \rightarrow MCO_3 + 2Na^{+} \qquad \textbf{(8-9)}$$

Carbonate precipitation is similar in operation to hydroxide precipitation, and is typically performed to remove metals such as cadmium or lead. For these metals, carbonate precipitation operates at a lower pH to achieve effluent concentrations similar to those achieved by hydroxide precipitation. Carbonate precipitation and hydroxide precipitation are sometimes performed in conjunction, which may improve the overall performance of certain systems.

Carbonate precipitation is less popular than hydroxide precipitation due to the higher cost of treatment reagents and certain operational problems, such as the release of carbon dioxide gas, which can result in foaming and/or floating sludge. Also, since many metal carbonates are more soluble than sulfides or hydroxides, this process is not effective for all metals.

Sodium Borohydride Precipitation. Sodium borohydride precipitation uses sodium borohydride as a reducing agent to precipitate metals from solution as insoluble elemental metals. This reaction is shown in the following equations:

$$4M^{2+} + NaBH_4 + 2H_2O \rightarrow NaBO_2 + 4M + 8H^{+} \qquad \textbf{(8-10)}$$

$$4M^{2+} + NaBH_4 + 8OH^{-} \rightarrow NaBO_2 + 4M + 6H_2O \qquad \textbf{(8-11)}$$

This process is similar in operation to hydroxide precipitation. Borohydride precipitation is usually performed in a pH range of 8 to 11 to efficiently utilize borohydride. The optimum pH is determined by testing borohydride usage, reaction time, and effluent quality.

Sodium borohydride precipitation effectively removes lead, mercury, nickel, copper, cadmium, and precious metals, such as gold, silver, and platinum, from wastewater. This process has also been reported to reduce sludge generation by 50 percent over traditional precipitation. However, sodium borohydride precipitation is much more expensive than other precipitation methods.

8.3.1.1 Gravity Clarification for Solids Removal

Gravity sedimentation to remove precipitated metal hydroxides is the most common method of clarification (solids removal) used in MP&M facilities. Typically, two types of sedimentation devices are used: inclined-plate (e.g., lamella) clarifiers and circular clarifiers. Figure 8-15 shows a circular clarifier. The continuous chemical precipitation shown in Figure 8-13 uses a lamella clarifier. Lamella clarifiers often provide superior clarification and are more common at MP&M facilities due to the smaller area required when compared to circular clarifiers. Lamella clarifiers typically require 65 to 80 percent of the area required for a circular clarifier. Their design promotes laminar flow through the clarifier, even when the water throughput is relatively high. Lamella clarifiers permit overflow rates at least two to four times greater than conventional clarifiers.

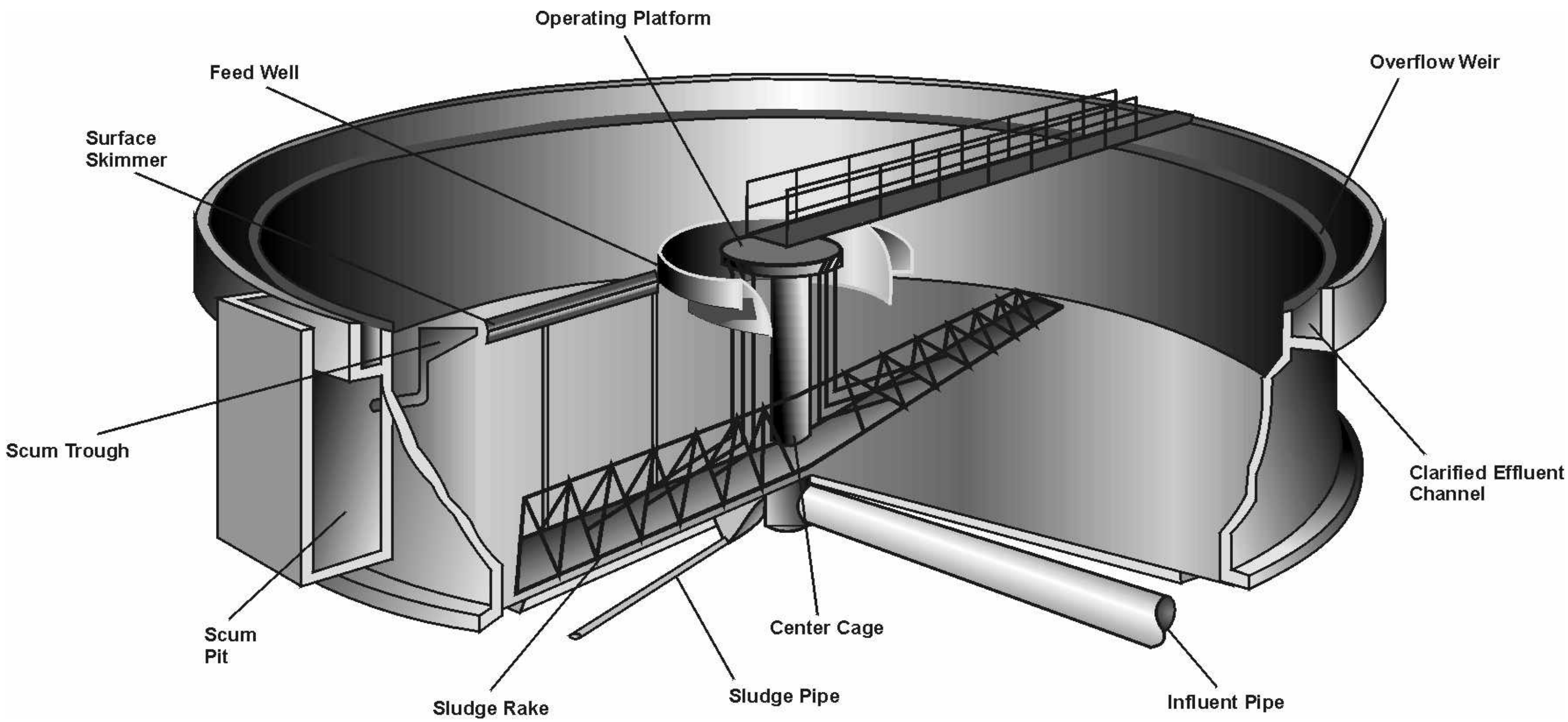

Figure 8-15. Clarifier

Lamella clarifiers contain inclined plates oriented at angles varying between 45 and 60 degrees from horizontal. As the water rises through the plates, the solids settle on the lower side of the plate. The clarified effluent continues up through the plate, passes over a weir, and is collected in an effluent holding tank. The solids collect on the lower side of the plate and slide downward due to the inclination of the plate. The solids collect on the bottom of the clarifier and are scraped into a sludge hopper before discharge to the thickener.

Overflow rates for lamella clarifiers vary from 1,000 to 1,500 gpd/ft^2 for metal hydroxide sludges, assuming the flow is uniformly distributed through the plate settlers. Clarifier inlets must be designed to distribute flow uniformly through the tank and plate settlers. In addition, since solids can build up on plate surfaces, the clarifier should be cleaned periodically. Otherwise, solids may become dislodged from the plates, and degrade effluent quality, and nonuniform buildup may adversely affect flow distribution through the plates.

8.3.1.2 Microfiltration for Solids Removal

Microfiltration can be used as an alternative to conventional gravity clarification after chemical precipitation. Microfiltration is a membrane-based process used to separate small suspended particles based on size and shape. Using an applied pressure difference across a membrane, water and small solute species pass through the membrane and are collected as permeate while larger particles such as precipitated and flocculated metal hydroxides are retained by the membrane and are recovered as concentrate. Microfiltration is similar to ultrafiltration (Section 8.2.5.4) but has a larger pore size.

Microfiltration removes materials ranging from 0.1 to 1.0 microns (e.g., colloidal particles, heavy metal particulates and their hydroxides). Most microfiltration membranes are made of homogeneous polymer material. The transmembrane pressure required for microfiltration typically ranges between 3 to 50 psi, depending on membrane pore size.

Microfiltration produces a concentrated suspended solid slurry that is typically discharged to dewatering equipment such as a sludge thickener and a filter press. The permeate can either be treated further to adjust the pH or be discharged, depending on local and state requirements. Figure 8-5 shows a typical membrane filtration system.

The microfiltration system includes: pumps and feed vessels; piping or tubing; monitoring and control units for temperature, pressure, and flow rate; process and cleaning tanks; and membranes. Membranes are specifically designed to handle various waste stream parameters, including temperature, pH, and chemical compatibility. Different types of membranes can be purchased, including hollow fiber, tubular, flat plate, and spiral wound. The configuration selected for a particular facility depends on the type of application. For example, tubular membranes are commonly used to separate suspended solids, whereas spiral wound membranes are used to separate oils from water. Microfiltration is more expensive than conventional gravity clarification. Membranes must be periodically cleaned to prevent fouling and ensure effective treatment.

8.3.2 Oil Removal

Operations such as machining and grinding, disassembly of oily equipment, and cleaning can generate wastewater containing organic machining coolants, hydraulic oils, and lubricating oils. In addition, shipbuilding facilities may commingle their oily bilge water with other shore-side operations, resulting in a mixed oily wastewater. Data collected during MP&M site visits, sampling episodes, and from the MP&M detailed surveys showed a variety of methods to treat oily wastewater. The primary treatment technologies are emulsion breaking and gravity flotation, emulsion breaking and dissolved air flotation, and ultrafiltration. EPA discussed these technologies in the preliminary treatment section (see Section 8.2.5).

8.3.3 Polishing Technologies

Polishing systems remove small amounts of pollutants that may remain in the effluent after treatment by technologies such as chemical precipitation and clarification and ultrafiltration. These systems can also act as a temporary measure to prevent pollutant discharge should the primary treatment technology fail due to a process upset or catastrophic event. The following is a description of end-of-pipe polishing technologies that are applicable to MP&M facilities.

8.3.3.1 Multimedia Filtration

Multimedia filtration systems are typically used to remove small amounts of suspended solids (metal precipitates) entrained in effluent from gravity clarifiers. Multimedia polishing filters are typically designed to remove 90 percent or greater of all filterable suspended solids 20 microns or larger at a maximum influent concentration of 40 mg/L. Wastewater is pumped from a holding tank through the filter. The principal design factor for the multimedia filter is the hydraulic loading. Typical hydraulic loadings range between 4 and 5 gpm/ft^2. Multimedia filters are cleaned by backwashing with clean water. Backwashing is timed to prevent breakthrough of the suspended solids into the effluent. Figure 8-16 shows a diagram of a multimedia filtration system.

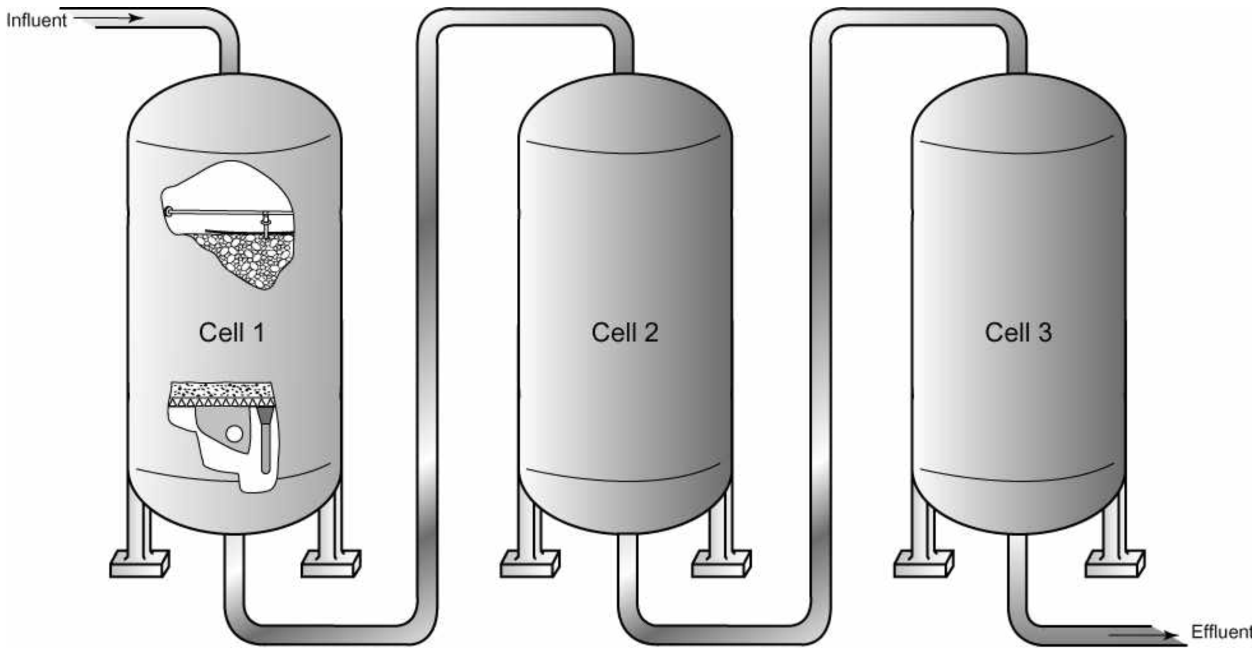

Figure 8-16. Multimedia Filtration System

8.3.3.2 Activated Carbon Adsorption

Activated carbon adsorption removes dissolved organic compounds from wastewater streams. For some MP&M facilities, carbon adsorption is used to polish effluent from ultrafiltration systems treating oily wastewater. During adsorption, molecules of a dissolved compound adhere to the surface of an adsorbent solid. Activated carbon is an excellent adsorption medium due to its large internal surface area, generally high attraction to organic pollutants, and hydrophobic nature (i.e., water will not occupy bonding sites and interfere with the adsorption of pollutants). Pollutants in the wastewater bond on the activated carbon grains until all the surface bonding sites are occupied. At that point, the carbon is considered to be "spent." Spent carbon requires regeneration, which results in reduced adsorption capacity compared to fresh carbon. After several regenerations, the carbon is disposed.

The carbon is placed in granular carbon system vessels, forming a "filter" bed. Vessels are usually circular for pressure systems or rectangular for gravity flow systems. For wastewater treatment, activated carbon is typically packed into one or more filter beds or columns; a typical treatment system consists of multiple filter beds in series. Wastewater flows through the filter beds and is allowed to come in contact with all portions of the activated carbon. The activated carbon in the upper portion of the column is spent first (assuming flow is downward), and progressively lower regions of the column are spent as the adsorption zone moves down the unit. When pollutant concentrations at the bottom of the column begin to increase above acceptable levels, the entire column is considered spent and must be regenerated or removed.

8.3.3.3 Reverse Osmosis

Reverse osmosis is a membrane separation technology used by the MP&M industry as an in-process step or as an end-of-pipe treatment. Section 8.2 discusses in-process reverse osmosis. In an end-of-pipe application, reverse osmosis is typically performed to recycle water and reduce discharge volume rather than recover chemicals. The effluent from a conventional treatment system generally has a TDS concentration unacceptable for most rinsing operations, and cannot be recycled. TDS concentrations can be reduced by reverse osmosis membranes with or without some pretreatment, and the resulting effluent stream can be used for most rinsing operations.

8.3.3.4 Ion Exchange

Ion exchange is used for both in-process and end-of-pipe applications. Section 8.2 discusses in-process ion exchange. Ion exchange may also be used as an end-of-pipe final polishing step, or to recycle water. This technology generally uses cation resins to remove metals but sometimes both cation and anion columns are used. The regenerant from end-of-pipe ion exchange is not usually amenable to metals recovery as it typically contains multiple metals at low concentrations.

8.3.4 Sludge Handling

EPA discusses the following sludge-handling technologies in this section.

- Gravity thickening;
- Pressure filtration;
- Sludge drying; and
- Vacuum filtration.

8.3.4.1 Gravity Thickening

Gravity thickening is a physical liquid-solid separation technology used to dewater wastewater treatment sludge. Sludge is fed from a primary settling tank or clarifier to a thickening tank, where gravity separates the supernatant (liquid) from the sludge, increasing the sludge density. The supernatant is returned to the primary settling tank or the head of the treatment system for further treatment. The thickened sludge that collects on the bottom of the tank is pumped to additional dewatering equipment or contract hauled for disposal. Figure 8-17 shows a diagram of a gravity thickener.

Gravity thickeners are generally used in facilities where the sludge is to be further dewatered by a mechanical device, such as a filter press. Increasing the solids content in the thickener substantially reduces capital and operating costs of the subsequent dewatering device and also reduces the hauling cost. This process is potentially applicable to any MP&M site that generates sludge.

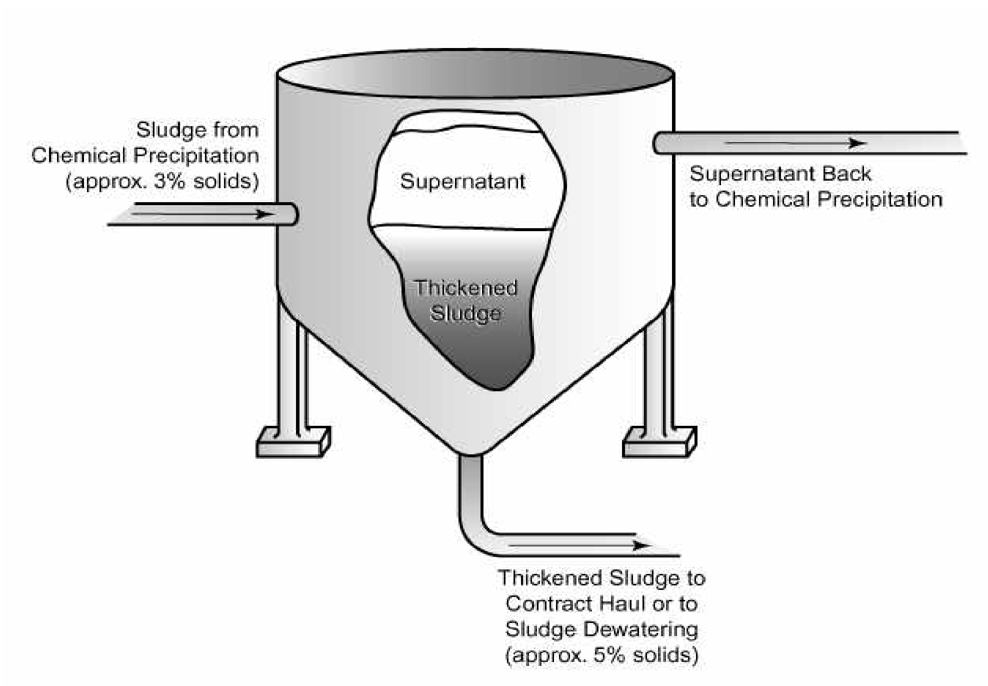

Figure 8-17. Gravity Thickening

8.3.4.2 Pressure Filtration

The filter press is the most common type of pressure filtration used in the MP&M industry for dewatering wastewater treatment sludges. A filter press consists of a series of parallel plates pressed together by a hydraulic ram (older models may have a hand crank), with cavities between the plates. Figure 8-18 shows a diagram of a plate-and-frame filter press. The filter press plates are concave on each side to form cavities and are covered with a filter cloth. At the start of a cycle, a hydraulic pump clamps the plates tightly together and a feed pump forces a sludge slurry into the cavities of the plates. The liquid (filtrate) escapes through the filter cloth and grooves molded into the plates and is forced by the pressure of the feed pump (typically around 100 psi) to a discharge port. The solids are retained by the cloth and remain in the cavities. This process continues until the cavities are packed with sludge solids. An air blow-down manifold is used on some units at the end of the filtration cycle to drain remaining liquid from the system, further drying the sludge. The pressure is then released and the plates are separated. The sludge solids or cake is loosened from the cavities and falls into a hopper or drum. A plate filter press can produce a sludge cake with a dryness of approximately 25 to 40 percent solids for metal hydroxides precipitated with sodium hydroxide, and 35 to 60 percent solids for metal hydroxides precipitated with calcium hydroxide. The final solids content depends on the length of the drying cycle. Filter presses are available in a very wide range of capacities (0.6 ft^3 to 20 ft^3). A typical operating cycle is from 4 to 8 hours, depending on the dewatering characteristics of the sludge. Units are usually sized based on one or two cycles per day.

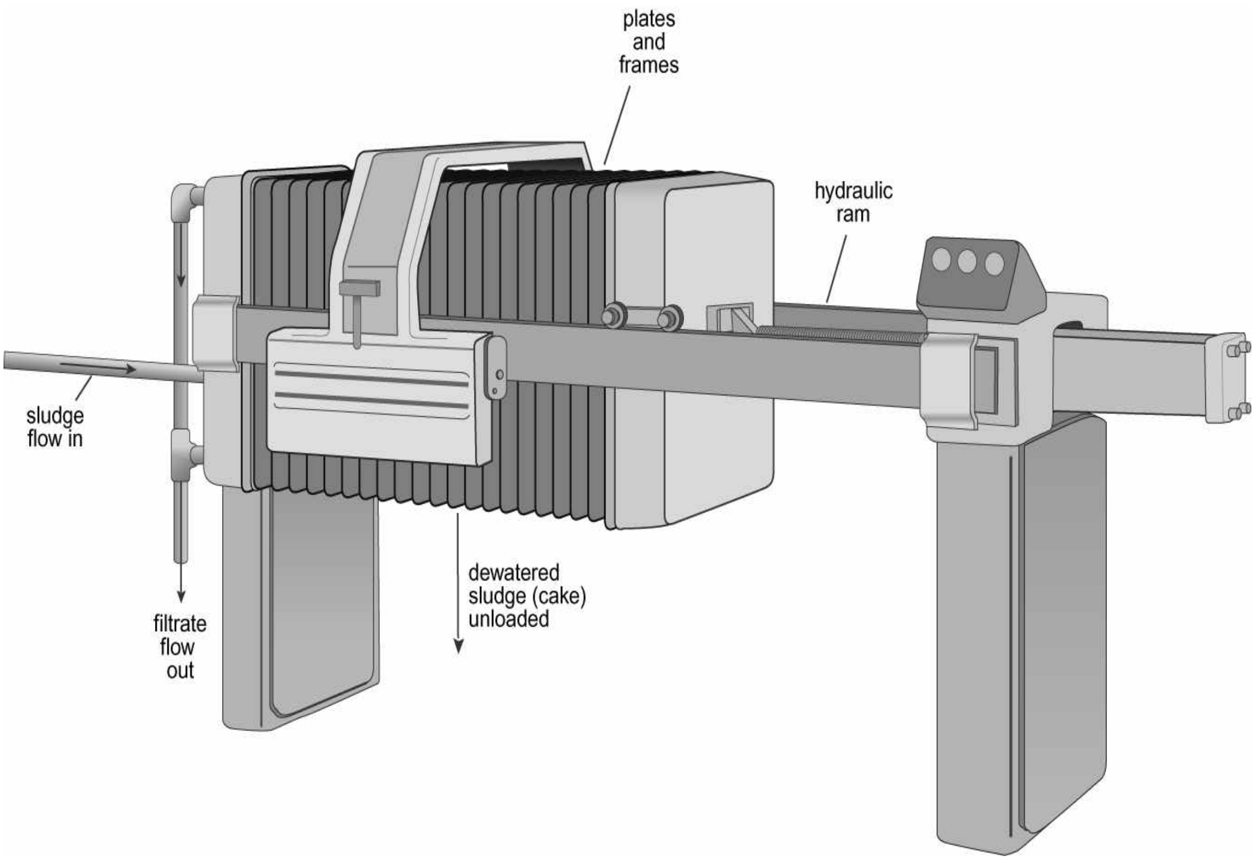

Figure 8-18. Plate-and-Frame Filter Press

8.3.4.3 Vacuum Filtration

Vacuum filtration is performed at some MP&M sites to reduce the water content of sludge, increasing the solids content from approximately 5 percent to between 20 and 30 percent. These MP&M sites generally use cylindrical drum vacuum filters. The filters on these drums are typically either made of natural or synthetic fibers or a wire-mesh fabric. The drum is dipped into a vat of sludge and rotates slowly. A vacuum inside the drum draws sludge to the filter. Water is drawn through the filter to a discharge port, and the dewatered sludge is scraped from the filter. Because dewatering sludge with a vacuum filter is relatively expensive per kilogram of water removed, the liquid sludge is frequently gravity-thickened prior to vacuum filtration. Figure 8-19 shows a typical vacuum filter. Vacuum filters are frequently used both in municipal treatment plants and in a wide variety of industries. They are most commonly used in larger facilities, which may have a thickener to double the solids content of clarifier sludge before vacuum filtering. Often a precoat is used to inhibit filter binding.

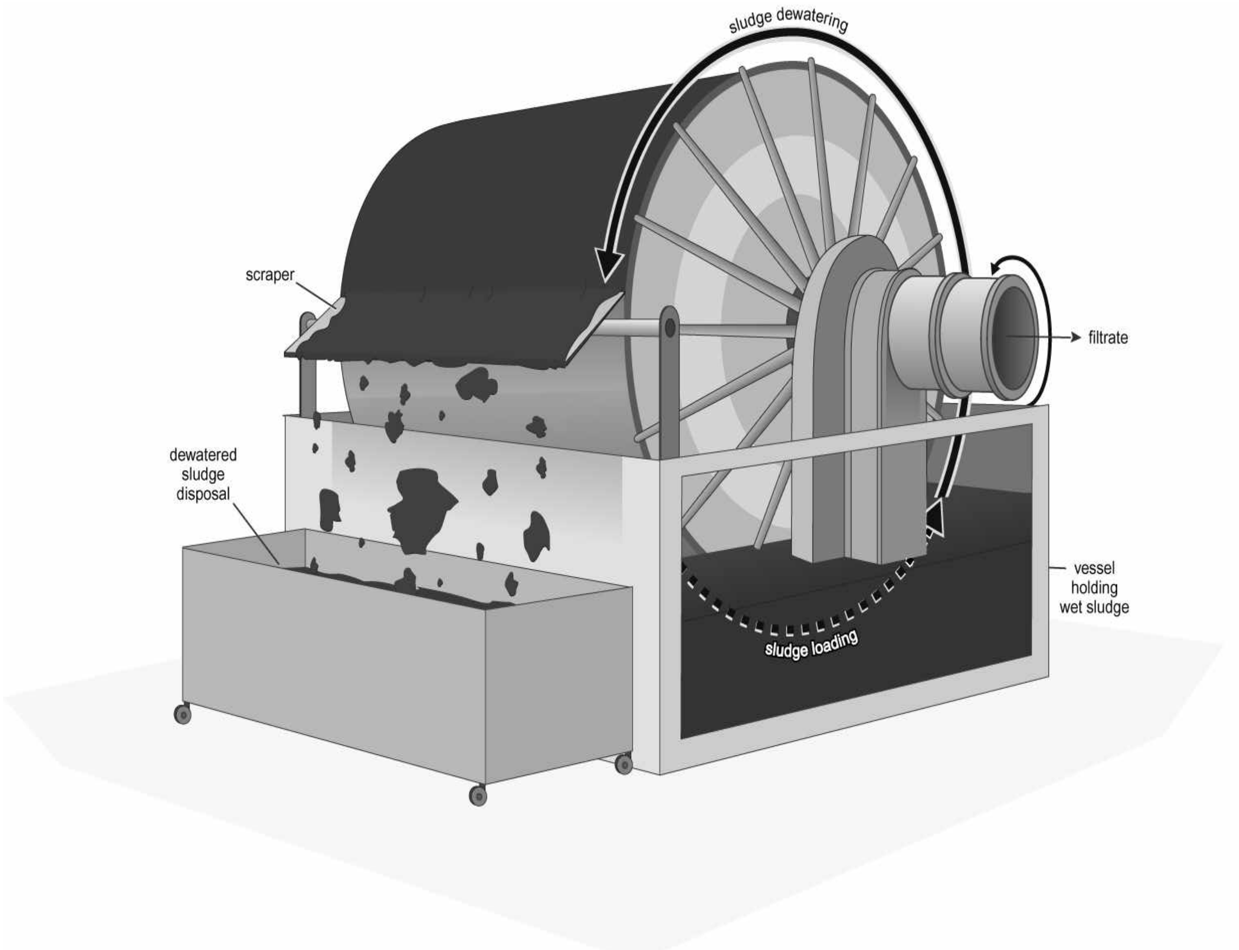

Figure 8-19. Rotary Vacuum Filter

Maintenance of vacuum filters involves cleaning or replacing the filter media, drainage grids, drainage piping, filter parts, and other parts. Since maintenance time may be as high as 20 percent of total operating time, facilities may maintain one or more spare units. If this technology is used intermittently, the facility may drain and wash the filter equipment each time it is taken out of service.

8.3.4.4 Sludge Drying

Wastewater treatment sludges are often hauled long distances to disposal sites. The transportation and disposal costs depend mostly on the volume of sludge, which is directly related to its water content. Therefore, many MP&M sites use sludge drying equipment following dewatering or vacuum filtration to further reduce the volume of the sludge. The solids content of the sludge dewatered on a filter press usually ranges from 25 to 60 percent. Drying equipment can produce a waste material with a solids content of approximately 90 percent.

There are several design variations for sludge drying equipment. A commonly used system consists of an auger or conveyor system to move a thin layer of sludge through a drying region and discharge it into a hopper. Various heat sources including electric, electric infrared, steam, and gas are used for sludge drying. Some continuous units are designed such that the sludge cake discharged from a filter press drops into the feed hopper of the unit, making the overall dewatering process more automated. System capacities range from less than 1 ft^3/hr to more than 20 ft^3/hr of feed. Sludge drying equipment requires an air exhaust system due to the fumes generated during drying.

8.4 References

1. U.S. Environmental Protection Agency. Facility Pollution Prevention Guide. EPA-600-92-088, Washington, DC. 1992.

2. U.S. Environmental Protection Agency. Development Document for Effluent Limitations Guidelines and Standards for the Nonferrous Metals Forming and Metal Powders Point Source Category. EPA 440-1-86-019, September, 1996.

3. Cherry, K.F. Plating Waste Treatment. Ann Arbor Sciences Publishers, Inc., Ann Arbor, Michigan, 1982.

4. Freeman, H.M. Standard Handbook of Hazardous Waste Treatment and Disposal. McGraw Hill Book Company, New York, 1989.

5. Cushnie, George C., Pollution Prevention and Control Technology for Plating Operations, National Center for Manufacturing Sciences, 1994.

6. Eckenfelder, W. Wesley. Industrial Water Pollution Control. McGrawHill, 2000.

7. Letterman, Raymond D., Water Quality and Treatment: A Handbook of Community Water Supplies, Fifth Edition, Mc-Graw Hill, 1999.